ERIC Document Resume	See Instruction Sheet	DATE OF RESUME	DATE RECEIVED

A. PUBLICATION DATA

1. ERIC NUMBER	2. ORIGINATOR CONTROL NO(S).	3. IDENTIFICATION NO.
ED001386	SC 2127	N.A.

4. AUTHOR(S):
Lewis D. Eigen, and others

5. TITLE OF DOCUMENT ABSTRACTED:
Research Summary Number 1

6. PUBLICATION TITLE:
N.A.

7. EDITOR(S):
N.A.

8. PLACE OF ORIGIN
ORG. Collegiate School
ST. 241 W. 77th Street
CITY, STATE New York, New York

9. PUBLISHER OR SOURCE
Automated Teaching Project, Collegiate School, 241 W. 77th St., New York, NY

10. VOL.	11. PAGES	12. MO./YR.	13. TOTAL PP.

TELE. EXT.
INST/LOC CODE

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TYPE OF REPORT
PROPOSAL ☐
IN-PROGRESS ☐
FINAL ☒
FOLLOW-UP ☐

OTHER ERIC REFERENCES:

ERIC SATELLITE CODE

B. INDEXING DATA

14. SUBJECT AREA

15. TYPE OF ENDEAVOR
report

16. INDEXING TERMS (6-12)

teaching machines	learning		
programed texts	costs		
cheating	student attitudes	teacher attitudes	

17. ABSTRACT (MAX. 250 WORDS)

Relative effectiveness of mechanical teaching machines and programmed textbooks as teaching devices, and the effect of grade level on learning by means of these automated teaching methods were investigated. The effective difference between the mechanical, write-in teaching machine and the programed text is that cheating is less likely to occur with the mechanical device. However, researchers have hypothesized that cheating, should it occur, does not affect the quality of learning. Seventy-four male subjects from Collegiate School in New York, the majority from middle and upper middle class backgrounds, with mean IQ of the group 126.9, were chosen for the study. None of the subjects had previous experimental history.

The programs for the machines were rolled in sections of approximately 150 frames.

The machines were located in a special room provided for the purpose in a building adjacent to the Collegiate School, with each machine placed on an individual desk. Programmed textbooks were mimeographed and contained seven levels to the page with questions and answers on separate pages requiring two turns per frame.

Subjects were assembled by grade levels and were told that they would begin learning some mathematical material in a new way. They were assured that the results of their work would not affect their school grades.

Conclusions of the study show that learning takes place with equal efficiency whether automated teaching sequence is presented by programmed text or mechanical write-in machine. The mean time for the machine group exceeded the mean time for the programmed text by more than 37 minutes, leading to the conclusion that these mechanical devices hindered the efficiency of learning by taking more of the student's time. Tables and charts illustrate the report.

ERIC No.

18. SOURCE OF ABSTRACT

C. FUNDING DATA

19. SUPPORTING ORGANIZATION	20. DIVISION OR DEPT.	21. CONTRACT NO. / PROJECT NO.
	22. TOTAL COST OF PROJECT	
	23. DURATION OF PROJECT	U.S. Department of Health, Education, and Welfare Office of Education

AUTOMATED TEACHING PROJECT
COLLEGIATE SCHOOL
241 West 77th Street
New York 24, New York

ED001386

ADD

June 1960

RESEARCH SUMMARY NUMBER 1*

by

Lewis D. Eigen and P. Kenneth Komoski

The research summarized in this report was designed to investigate two aspects of automated teaching:

(1) The relative effectiveness of mechanical teaching machines and programmed textbooks as teaching devices.

(2) The effect of grade level on learning by means of these automated teaching methods.

One of the questions which has frequently been asked is whether there is a significant difference in learning when the same material is presented by a mechanical, write-in teaching machine or a programmed text. The effective difference between these two types of teaching machims is that cheating is less likely to occur with the mechanical device. Cheating here refers to the possibility of looking ahead to the correct response before answering a question or changing a response after seeing the correct one. However, some researchers have hypothesized that such cheating, should it occur, does not affect the quality of learning.

At the present time there is no evidence which justifies the practice of withholding certain topics for teaching at the more advanced grade levels. This is understandable where basic knowledge is required before proceeding. However, if no preliminary learning is necessary, one can assume that the grade level at which the new material is introduced does not significantly affect the ability of students to learn it.

*This study was made possible through aid of The Fund for the Advancement of Education.

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SUBJECTS

A total of seventy-four male subjects from the Collegiate School in New York City (twenty-five ninth grade students, twenty-three tenth grade students, and twenty-six eleventh grade students) were used. The majority of the subjects came from middle class and upper middle class economic backgrounds. The mean Otis IQ for the entire group of subjects was 126.8. None of the subjects had any previous experimental history.

APPARATUS

The machines used were proto-models of a Skinner-type write-in machine, manufactured by the Rheem Califone Corporation. The programs for the machines were printed by a standard spirit duplicator process. The programs were rolled in sections of approximately 150 frames per section. The machines were located in a special room provided for the purpose in a building adjacent to the Collegiate School. Each machine was placed on an individual desk.

The programmed textbooks were mimeographed and contained seven levels to the page with questions and answers on separate pages requiring two page turns per frame. These textbooks were used in schoolrooms in the Collegiate School.

The program used was Sets, Relations and Functions, by Lewis D. Eigen. This program consists of 707 frames.

PROCEDURE

Subjects in each grade level were assigned at random to one of two experimental groups, a write-in teaching machine group or a programmed text group. Six experimental groups were formed in this way (these are designated 9P, 9M, 10P, 10M, 11P, and 11M). Two students, one from group 9P and the other from group 11P, were dropped from the experiment because of illness. The mean Otis IQ for the six respective groups (less the two who were dropped) was as follows:

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TABLE 1

MEAN OTIS IQ

	9	10	11
M	123.2	127.8	127.0
P	126.8	126.9	129.3

Subjects were assembled by grade levels and told that on the following day they would begin learning some mathematical material in a new way. They were also told that the results of their work would not affect their school grades in any way. Each was also acquainted with the particulars of the group to which he had been assigned as well as the general nature of this method of teaching. Each subject was individually assigned a schedule that permitted him to work on this project for two forty-minute school periods daily. Each subject was assigned a number. Copies of these schedules and number assignments were posted on bulletin boards throughout the school.

On the following day each subject proceeded, according to his schedule, to either the machine room or to a classroom designated for programmed textbook instruction. One faculty supervisor was present in each of the two rooms at all times although he answered no questions about the material. Of the forty minute experimental session, only 30 minutes were permitted for working time on the programs. Thus, each subject worked for two one-half hour sessions daily. Each subject kept an individual record card for each session (see Figure 1 below).

FIGURE 1

NAME_____ NO._____

DATE_____

Item Start_____ Item End_____

Time minus_____ Cause_____

Time minus_____ Cause_____

These cards were kept on file in the appropriate room so that a student might know where in his program he was to begin work at each session. If there was any delay due to machine failure or other unforeseen circumstances, the time of delay was subtracted by the supervisor and entered on the record card. Subjects were not permitted to repeat any section or sections of the program. Each student proceeded in this manner until he had finished the entire program. If any subject completed the program in the middle of an experimental session, the supervisor subtracted the time remaining for the session by entering this time under the time minus column of the record card. On the day following completion of the program, each student took two tests: a post test on the material covered in the program (Items 1-20, Appendix C) and a transfer test comprised of items which were not specifically covered but which demanded the concepts and skills developed by the program for successful completion (Items 21-30, Appendix C). An attitudinal scale (Appendix B) was given to all subjects between one and three days after completion of the program. Thus, four measures were available for each subject: a post test score (PTR), a measure of the amount learned; a transfer test (PTT), a measure of the ability to transfer the materials after having proceeded through the program; an attitude measure (A); and a time measure (T), the amount of time the subject took to complete the program.

ANALYSIS

Twelve null hypotheses were formulated for testing. They were:

H_0^1(PTR): There is no effect of treatment (programmed text or mechanical write-in machine) upon learning.

H_0^2(PTR): There is no effect of grade level upon learning.

$H_0^{1\times2}$(PTR): There is no interaction effect of treatment and grade level upon learning.

H_0^1(PTT): There is no effect of treatment upon the subjects' ability to transfer the materials.

H_0^2(PTT): There is no effect of grade level upon the subjects' ability to transfer the materials.

$H_0^{1\times2}$(PTT): There is no interaction effect of treatment and grade level upon the subjects' ability to transfer the materials.

H_0^1(T): There is no effect of treatment upon the time it took the subjects to proceed through the program.

H_0^2(T): There is no effect of grade level upon the time it took the subjects to proceed through the program.

$H_0^{1\times2}$(T): There is no interaction effect of treatment and grade level upon the time it took the subjects to proceed through the program.

H_0^1(A): There is no effect of treatment upon attitude.

H_0^2(A): There is no effect of grade level upon attitude.

$H_0^{1\times2}$(A): There is no interaction effect of treatment and grade level upon attitude.

The testing of these hypotheses was accomplished by means of the 2×3 analysis of variance which uses the experimental design of Rosedith Sitgreaves and Herbert Solomon of Teachers College, Columbia University (Appendix A). Computation was done using an IBM 650 computer.[Δ] The data and the results of the analysis of variance for each criterion are summarized in Tables 2-5. For any criterion Y, H_0^1(Y) is tested by means of t_1 for the criterion Y. H_0^2(Y) is tested by means of F_2 for the criterion. $H_0^{1\times2}$(Y) is tested by means of $F_{1\times2}$ for the criterion. The value of t_1 necessary for significance at the .05 level is 1.997; the value necessary at the .01 level is 2.654. Value of F_2 and $F_{1\times2}$ necessary for significance at the .05 level is 3.14; the value necessary for significance at the .01 level is 4.95. The t table is entered with 66 degrees of freedom and the F table is entered with 2 and 66 degrees of freedom.

[Δ] Through the courtesy of the International Business Machine Corp., the facilities of the Watson Scientific Computing Laboratory, Columbia University, have been made available to the project.

The .05 level of significance was considered sufficient grounds for the rejection of a hypothesis. On this basis, the evidence (Tables 2-5) seems to indicate that the following hypotheses should be rejected: $H_0^2(PTT)$, $H_0^1(T)$, $H_0^{1\times2}(T)$, $H_0^1(A)$, $H_0^2(A)$, and $H_0^{1\times2}(A)$.

Frequency distributions for the four criteria are given in Figures 2-5.

CONCLUSIONS

There seems to be no evidence necessitating the rejection of $H_0^1(PTR)$ and $H_0^1(PTT)$. Therefore, it would seem that learning takes place with equal efficiency whether an automated teaching sequence is presented by programmed text or mechanical write-in machine. The weighted mean ($\bar{X}_w$) of the mechanical machine was lower than that of the programmed text group for both cases (PTR and PTT; Tables 2 and 3). Because both $H_0^1(T)$ and $H_0^1(A)$ have been rejected, and the mean time for the machine group exceeded the mean time for the programmed text group by more than 37 minutes, it may be concluded that these mechanical devices hindered the efficiency of learning by taking more of the student's time. The fact that the mean attitude score for the programmed text group was more positive than that of the machine group reinforces this conclusion.

These results may be somewhat misleading. There were mechanical failures in several machines during the experiment which caused considerable frustration for some students. For example, one student said, "May I please go back and do the last section over again? I was so busy cussing out the machine that I didn't learn anything." Well-designed smoothly functioning machines should greatly reduce such negative attitudes while also increasing efficiency. Such machines will no doubt be available in the very near future.* However, it would seem that even a perfect write-in machine would teach no better than a programmed text presenting the same material.

Since both methods seem to be equally effective, in which should a school system invest? Although the initial cost of the mechanical

*The experimenters have made numerous recommendations to the manufacturers of the proto-models used in this experiment. As a result, the production models of the machines should be greatly improved.

devices might be considerable, it would probably be less expensive to use mechanical devices than programmed texts over a long period of time. A program in a machine is subject to less hard wear by students than the constantly handled text. However, the programmed text has several advantages if it is used for purposes of research when planning new programs and for adapting automated teaching to individual schools.

Because there was no reason to reject H_0^2(PTR), the traditional concept that certain materials are best taught at a given grade level needs serious reexamination. Within the limits of this experiment, grades 9-11, there seems to be no significant effect of grade level upon learning. This would support the view that unless preliminary learning is required for a particular subject matter, the grade at which learning occurs is irrelevant. However, the rejection of H_0^2(PTT) would indicate that transfer ability of the materials learned is significantly affected by the grade level. An examination of the weighted grade level means in Table 3 shows that the eleventh grade was superior in transfer ability to the tenth grade which was, in turn, superior to the ninth grade. This last difference, however, was not significant ($t = .489$). This is understandable, since the eleventh grade students, having studied more mathematics, have a greater background and more experience with which to transfer the materials than the tenth grade, and similarly, the tenth grade more than the ninth. For this reason, determining the grade level at which to teach a particular unit of subject matter should be based on the transfer ability of the students and not on the vague notion of difficulty of the material. Moreover, if students were to have this background of experience before the time of learning, theoretically at least, they would transfer the materials on the basis of their previous learning experiences and independently of their age or grade level. Further research in this area is needed to determine the effect, if any, of age on transfer, previous learning experiences being discounted.

There seems to be little effect of grade level upon the length of time needed to learn. This is evidenced by the time required to complete the program, (T). Since F_2 of Table 4 is so close to 0, within the limits of the experiment it can be concluded that the efficiency of learning in terms of time is not affected by grade

level. The rejection of $H_0^2(A)$ is difficult to understand. An examination of the weighted grade level means (Table 5) yields small differences between the ninth and the eleventh grades and a large difference between the tenth grade and each of the other two grades in the experiment. Other than the fact that this tenth grade mean is the result of a random error, no suitable explanation can be found. Therefore, it is suggested that this phase of the experiment be repeated.

The rejection of $H_0^{1\times2}(T)$ indicates a definite interaction effect of grade level and treatment upon the time it took the students to proceed through the program. An examination of the separate group weighted means (Table 4) indicates that within the machine group, the eleventh grade was faster than the tenth grade which was, in turn, faster than the ninth grade. However, the reverse order was prevalent with respect to the programmed text group. Possibly this is because the oldest students were able to master the physical aspect of the machine, and since they could operate the machines more efficiently, they worked more quickly. The fact that the reverse order held true with respect to the programmed text group defies explanation at this point. It is possible that the eleventh graders, having more mathematics background, might have seen more in the materials that were presented and so, lingered over them longer. This, however, is at best an inadequate explanation and certainly more investigation is needed.

The rejection of $H_0^{1\times2}(A)$ presents a difficulty similar to the rejection of $H_0^2(A)$. At this time, there seems to be no reasonable explanation for this phenomenon.

The conclusions drawn in this paper have referred to automated teaching in general. In accepting these results, caution should be observed because a generalization has been made from a program in modern mathematics to the entire field of automated teaching. While there seems to be no theoretical difference between a program in modern mathematics and programs in other subjects, it would seem advisable to repeat this experiment with other programs. This would make it possible to extrapolate to automated teaching programs in general with greater confidence. It is also possible that the particular style of programming has affected these results. Different

results could conceivably be obtained if another style of programming were used, even with the same subject matter.

Examination of the frequency distributions of time and attitude (Tables 3 and 4) indicates that these two variables have a reasonably normal distribution. The requency distribution of the post test regular (Figure 2) indicates a nonnormal distribution. At best, a distribution of this type with an ideal teaching sequence would be a j curve which tails off to the left. This frequency distribution vaguely approximates such a j curve but the post test regular frequency distribution is translated to the left.

Observations based on the frequency distributions of the post test regular and the post test transfer (Figure 3) indicate that the program was somewhat ineffective with certain students. In theory, of course, this is due to faulty programming. However, one phenomenon is worthy of mention. Some of the students who failed to learn via the program were observed to proceed quickly to the next frame even after making an error. Two of these students questioned afterwards said that they didn't care whether their answers were right or wrong and that "the whole thing was foolish". This raises an interesting point. Theoretically, learning cannot take place without reinforcement. The most commonly used reinforcement in an automated teaching program is confirmation of each answer made by a student. Such confirmation is known to be a secondary rather than a primary reinforcement. That is, confirmation is not reinforcing in itself, but must be previously conditioned as a reinforcer. If, however, the necessary conditioning has not taken place the learning dependent on this conditioned reinforcer is bound to be greatly reduced. If this is so, one problem of automated teaching may be to maintain the strength of the secondary reinforcers used. This concern may become more acute in dealing with children who are culturally deprived or lacking in motivation. It may well be that one of the major jobs of the classroom teacher will be to condition the proper secondary reinforcers. The strength of the secondary reinforcers necessary for learning needs much investigation, and may well provide a considerable challenge to automated teaching.

TABLE 2

POST TEST REGULAR (PTR)

	9th Grade	10th Grade	11th Grade	
Machine	ΣX = 121 ΣX^2 = 1555 N = 13 $\bar{X}$ = 9.308	ΣX = 165 ΣX^2 = 2447 N = 12 $\bar{X}$ = 13.750	ΣX = 172 ΣX^2 = 2346 N = 14 $\bar{X}$ = 12.286	$\bar{X}$ = 11.781 $\bar{X}_w$ = 11.744
Programmed Text	ΣX = 139 ΣX^2 = 1935 N = 11 $\bar{X}$ = 12.636	ΣX = 129 ΣX^2 = 1735 N = 11 $\bar{X}$ = 11.727	ΣX = 159 ΣX^2 = 2419 N = 11 $\bar{X}$ = 14.455	$\bar{X}$ = 12.939 $\bar{X}_w$ = 12.939
	$\bar{X}$ = 10.972 $\bar{X}_w$ = 10.833	$\bar{X}$ = 12.738 $\bar{X}_w$ = 12.783	$\bar{X}$ = 13.371 $\bar{X}_w$ = 13.240	

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Methods	1	23.969	23.969
Grade Level	2	75.762	37.881
Interaction	2	92.388	46.194
Within Groups	66	1361.316	20.626

t_1 = -1.078 $\quad .20 < P < .30$

F_2 = 1.837 $\quad P > .05$

F_{1x2} = 2.240 $\quad P > .05$

TABLE 3

POST TEST TRANSFER (PTT)

	9th Grade	10th Grade	11th Grade	
Machine	$\Sigma X = 77$ $\Sigma X^2 = 877$ $N = 13$ $\bar{X} = 5.923$	$\Sigma X = 110$ $\Sigma X^2 = 1236$ $N = 12$ $\bar{X} = 9.160$	$\Sigma X = 152$ $\Sigma X^2 = 1828$ $N = 14$ $\bar{X} = 10.857$	$\bar{\bar{X}} = 8.647$ $\bar{X}_w = 8.690$
Programmed Text	$\Sigma X = 116$ $\Sigma X^2 = 1414$ $N = 11$ $\bar{X} = 10.546$	$\Sigma X = 92$ $\Sigma X^2 = 1010$ $N = 11$ $\bar{X} = 8.364$	$\Sigma X = 135$ $\Sigma X^2 = 1859$ $N = 11$ $\bar{X} = 12.273$	$\bar{\bar{X}} = 10.394$ $\bar{X}_w = 10.390$
	$\bar{\bar{X}} = 8.235$ $\bar{X}_w = 8.040$	$\bar{\bar{X}} = 8.762$ $\bar{X}_w = 8.780$	$\bar{\bar{X}} = 11.570$ $\bar{X}_w = 11.480$	

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Methods	1	54.516	54.516
Grade Level	2	156.396	78.198
Interaction	2	87.058	43.529
Within Groups	66	1459.722	22.117

$t_1 = -1.570$ $\quad .20 > P > .10$

$F_2 = 3.536$ $\quad .05 > P > .01$

$F_{1x2} = 1.968$ $\quad P > .05$

TABLE 4

TIME
(T)

	9th Grade	10th Grade	11th Grade	
Machine	ΣX = 4,524 ΣX^2 = 1,596,262 N = 13 $\bar{X}$ = 348.00	ΣX = 3,677 ΣX^2 = 1,154,881 N = 12 $\bar{X}$ = 306.42	ΣX = 3,997 ΣX^2 = 1,170,643 N = 14 $\bar{X}$ = 285.50	$\bar{\bar{X}}$ = 313.31 $\bar{X}_w$ = 312.77
Programmed Text	ΣX = 2,739 ΣX^2 = 692,628 N = 11 $\bar{X}$ = 249.00	ΣX = 3,069 ΣX^2 = 881,683 N = 11 $\bar{X}$ = 279.00	ΣX = 3,288 ΣX^2 = 1,014,148 N = 11 $\bar{X}$ = 298.91	$\bar{\bar{X}}$ = 275.64 $\bar{X}_w$ = 275.64
	$\bar{\bar{X}}$ = 298.50 $\bar{X}_w$ = 302.63	$\bar{\bar{X}}$ = 292.70 $\bar{X}_w$ = 293.00	$\bar{\bar{X}}$ = 292.21 $\bar{X}_w$ = 291.40	

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Methods	1	25,005.849	25,005.849
Grade Level	2	578.346	289.173
Interaction	2	39,083.176	19,541.588
Within Groups	66	146,697.533	2,226.899

t_1 = -3.351 $P < .01$

F_2 = 0.223 $P > .05$

F_{1x2} = 7.758 $P < .01$

TABLE 5

ATTITUDE
(A)

	9th Grade	10th Grade	11th Grade	
Machine	ΣX = 667 ΣX^2 = 34,485 N = 13 $\bar{X}$ = 51.31	ΣX = 723 ΣX^2 = 44,175 N = 12 $\bar{X}$ = 60.25	ΣX = 697 ΣX^2 = 35,661 N = 14 $\bar{X}$ = 49.79	$\bar{\bar{X}}$ = 53.78 $\bar{X}_w$ = 53.51
Programmed Text	ΣX = 643 ΣX^2 = 37,991 N = 11 $\bar{X}$ = 58.46	ΣX = 632 ΣX^2 = 36,738 N = 11 $\bar{X}$ = 57.46	ΣX = 646 ΣX^2 = 38,568 N = 11 $\bar{X}$ = 58.73	$\bar{\bar{X}}$ = 58.22 $\bar{X}_w$ = 58.21
	$\bar{X}$ = 54.88 $\bar{X}_w$ = 54.58	$\bar{X}$ = 58.85 $\bar{X}_w$ = 58.91	$\bar{X}$ = 54.26 $\bar{X}_w$ = 53.72	

ANALYSIS OF VARIANCE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Methods	1	350.734	350.734
Grade Level	2	320.266	160.133
Interaction	2	468.184	234.092
Within Groups	66	3,298.812	49.982

t_1 = -2.649 .02 > P > .01

F_2 = 3.204 .05 > P > .01

F_{1x2} = 4.683 .05 > P > .01

FIGURE 2 FREQUENCY DISTRIBUTIONS FIGURE 3

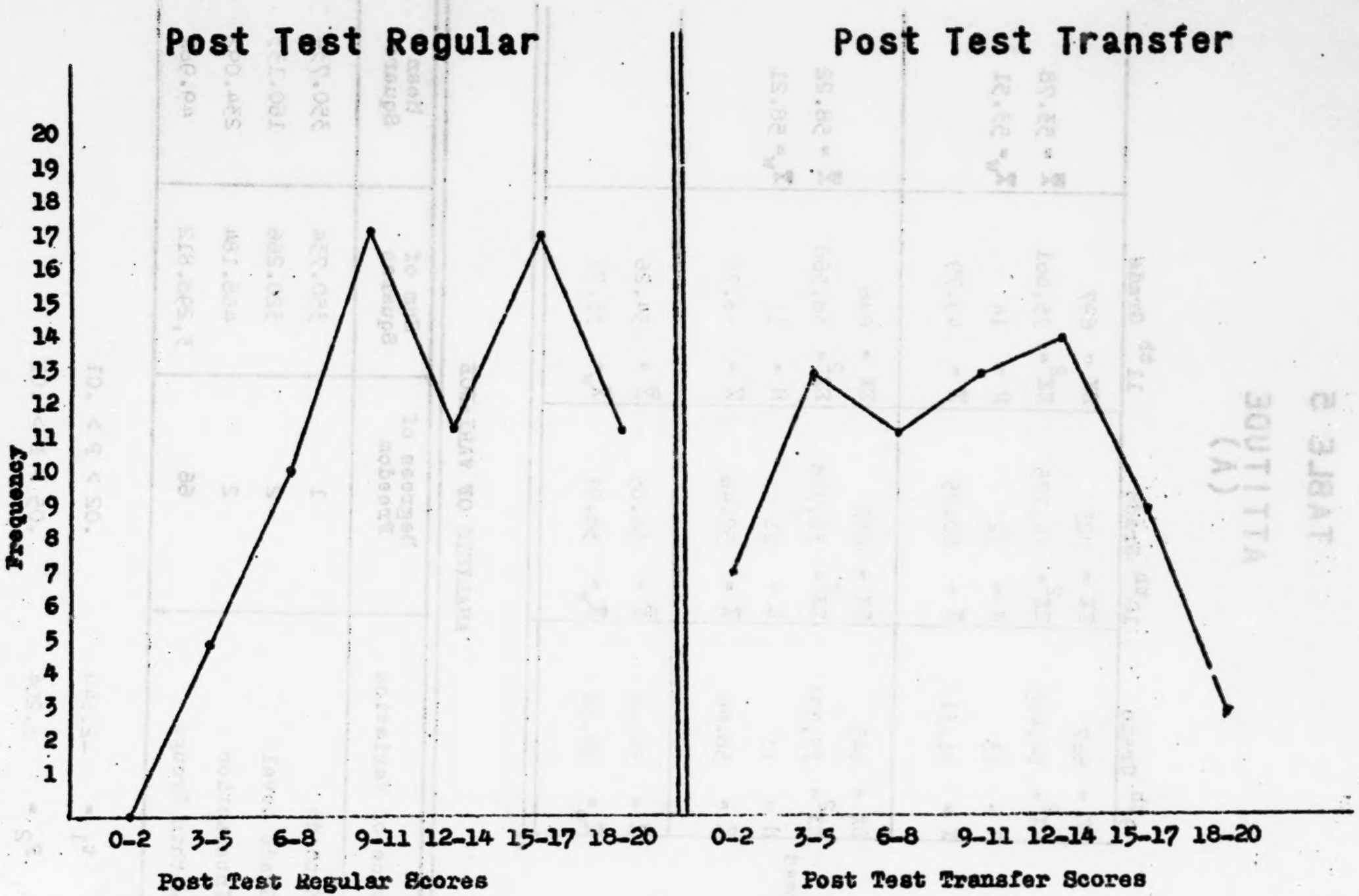


FIGURE 4

FREQUENCY DISTRIBUTION
Time

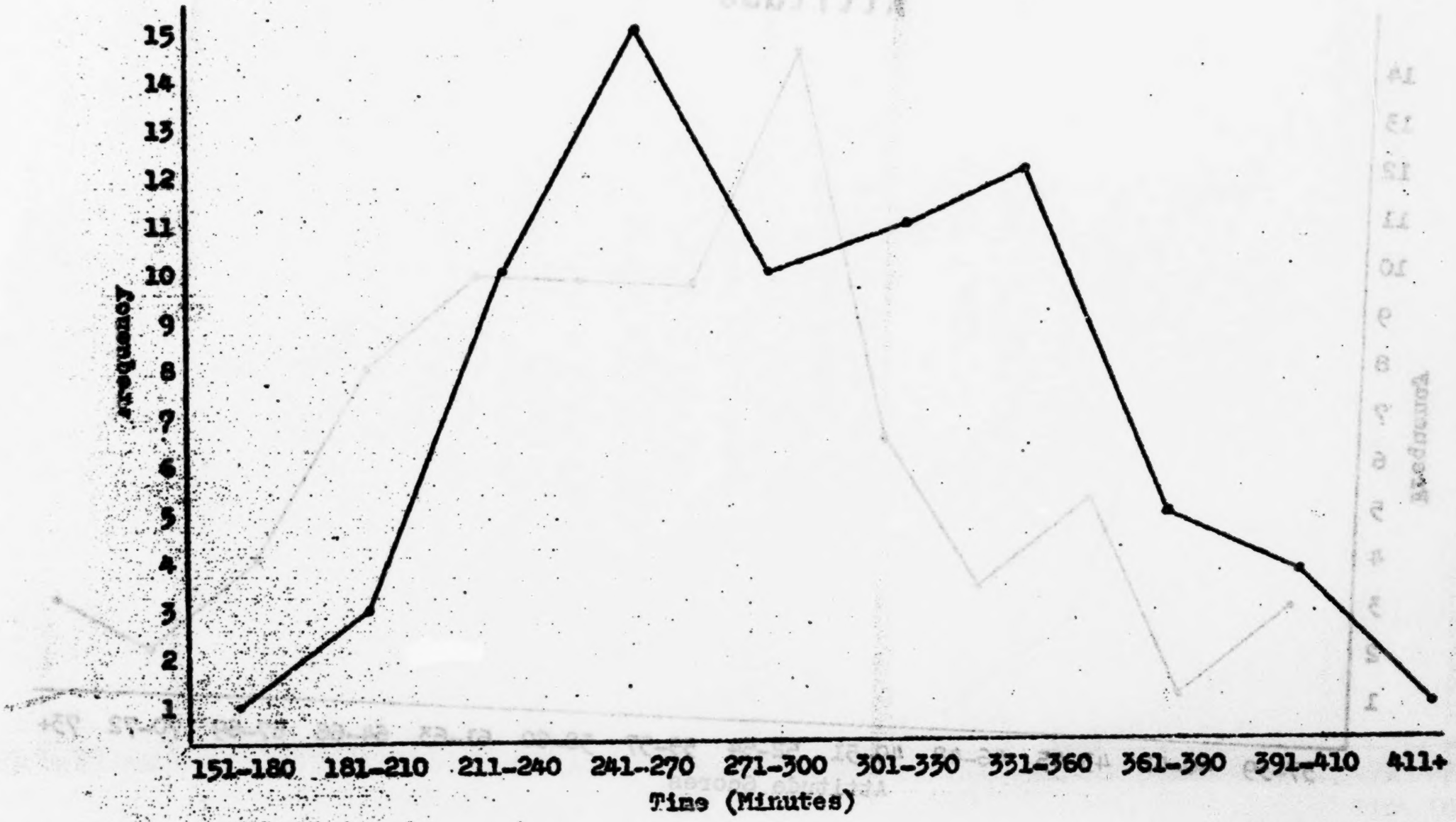
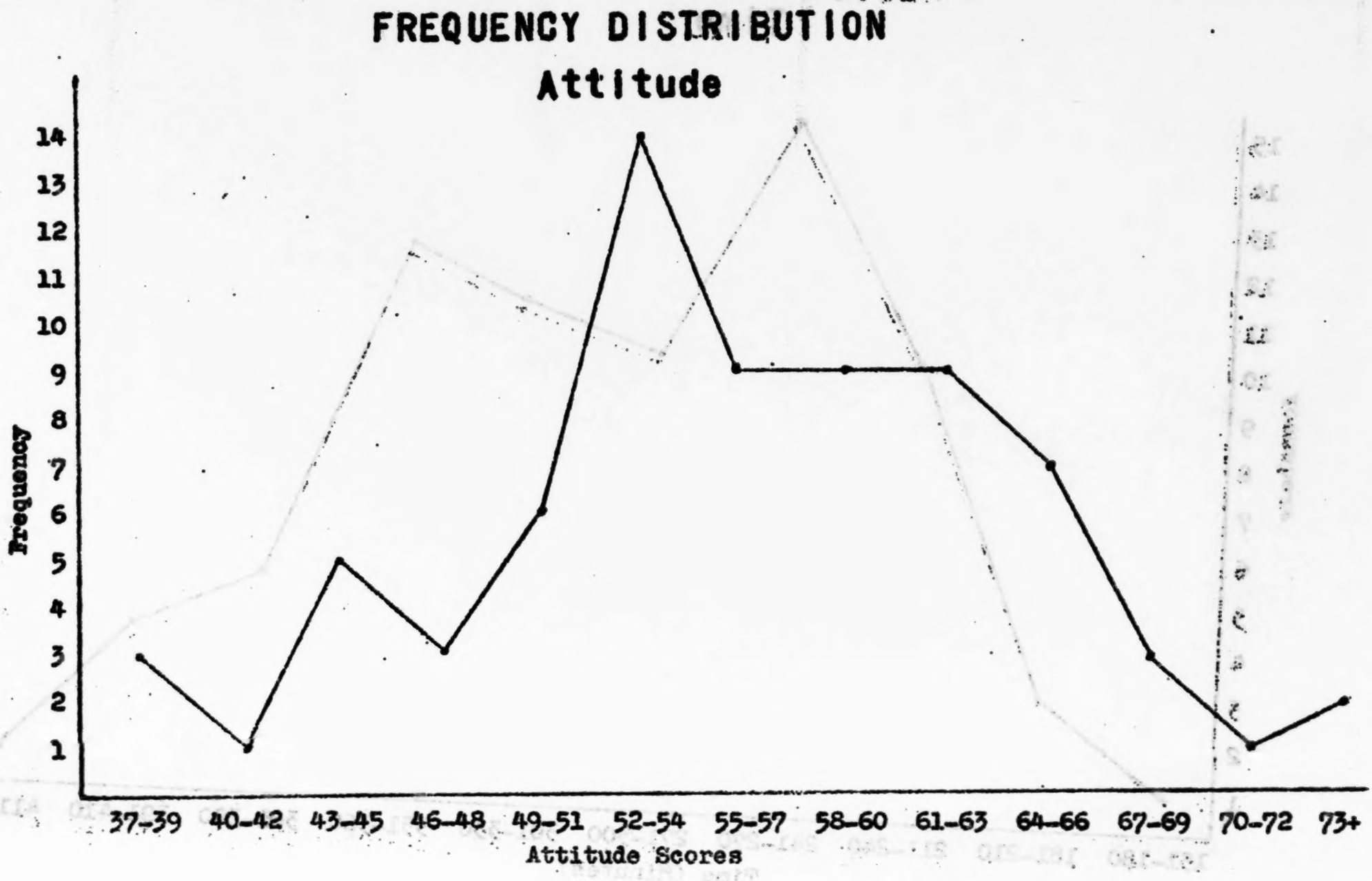


FIGURE 5


FREQUENCY DISTRIBUTION
Attitude
Frequency
14
13
12
11
10
9
8
7
6
5
4
3
2
1
37-39
40-42
43-45
46-48
49-51
52-54
55-57
58-60
61-63
64-66
67-69
70-72
73+
Attitude Scores

APPENDIX A

TWO WAY ANALYSIS OF VARIANCE WITH N_{ij} OBSERVATIONS IN EACH CELL

By

Rosedith Sitgreaves

and

Herbet Solomon

(From a forthcoming book on Analysis of Variance to be published by John Wiley and Sons, Inc.)

9.2 One Classificatory Variable Dichotomous

We consider now an experimental situation in which one of the experimental variables is dichotomous but the other is not. For example, we may be interested in the effect of geographic area and sex on an attitude measurement. For purposes of study, we might define the 6 subpopulations:

π_{11} : (Males in the New England States)

π_{21} : (Females in the New England States)

π_{12} : (Males in the Middle Atlantic States)

π_{22} : (Females in the Middle Atlantic States)

π_{13} : (Males in the South Atlantic States)

π_{23} : (Females in the South Atlantic States)

In general, in this situation, we have 2r subpopulations π_{ij} with i = 1 or 2, and j = 1,2,...,r. We assume that our measurement X is normally distributed in each of these subpopulations with variance σ^2 and expected value μ_{ij}, i = 1,2, and j = 1,2,...r. From (8.2.4) we have

(9.2.1)
$$\begin{aligned}
\mu_{11} &= \mu_{..} + \alpha_1 + \beta_1 + \gamma_{11} \\
\mu_{12} &= \mu_{..} + \alpha_1 + \beta_2 + \gamma_{12} \\
&\cdots\cdots\cdots \\
\mu_{1r} &= \mu_{..} + \alpha_1 + \beta_r + \gamma_{1r} \\
\mu_{21} &= \mu_{..} + \alpha_2 + \beta_1 + \gamma_{21} \\
\mu_{22} &= \mu_{..} + \alpha_2 + \beta_2 + \gamma_{22} \\
&\cdots\cdots\cdots \\
\mu_{2r} &= \mu_{..} + \alpha_2 + \beta_r + \gamma_{2r}
\end{aligned}$$

In this case, however,

since $\alpha_1 + \alpha_2 = 0$, we have $\alpha_1 = -\alpha_2 = \alpha$

$\gamma_{11} + \gamma_{21} = 0$, $\gamma_{11} = -\gamma_{21} = \gamma_1$

$\gamma_{12} + \gamma_{22} = 0$, $\gamma_{12} = -\gamma_{22} = \gamma_2$

$\cdots\cdots$ $\cdots\cdots$

$\gamma_{1r} + \gamma_{2r} = 0$, $\gamma_{1r} = -\gamma_{2r} = \gamma_r$, say.

We can rewrite (9.2.1) as

(9.2.2.)
$$\begin{aligned}
\mu_{11} &= \mu_{..} + \alpha + \beta_1 + \gamma_1 \\
\mu_{12} &= \mu_{..} + \alpha + \beta_2 + \gamma_2 \\
&\cdots\cdots\cdots \\
\mu_{1r} &= \mu_{..} + \alpha + \beta_r + \gamma_r \\
\mu_{21} &= \mu_{..} - \alpha + \beta_1 - \gamma_1 \\
\mu_{22} &= \mu_{..} - \alpha + \beta_2 - \gamma_2 \\
&\cdots\cdots\cdots \\
\mu_{2r} &= \mu_{..} - \alpha + \beta_r - \gamma_r
\end{aligned}$$

with $\sum_{j=1}^{r} \beta_j = 0$ and $\sum_{j=1}^{r} \gamma_j = 0$.

In carrying out an experiment to provide data for testing hypotheses about α, $\beta_1,\ldots,\beta_r$, and $\gamma_1,\ldots,\gamma_r$, we take a random sample of N_{11} individuals from π_{11}, N_{12} individuals from π_{12}, N_{1r} individuals from π_{1r}, N_{21} individuals from π_{21}, N_{22} individuals from $\pi_{22},\ldots,$ N_{2r} individuals from π_{2r}, with

$$N_{11} + N_{12} + \cdots + N_{1r} + N_{21} + N_{22} + \cdots + N_{2r} = N$$

We obtain the N Measurements.

$$\begin{array}{cccccccc}
X_{111} & X_{121} & \cdots & X_{121} & X_{211} & X_{221} & \cdots & X_{2r1} \\
X_{112} & X_{122} & \cdots & X_{122} & X_{212} & X_{222} & \cdots & X_{2r2} \\
\cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdots & \cdot \\
\cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdots & \cdot \\
\cdot & \cdot & \cdots & \cdot & \cdot & \cdot & \cdots & \cdot \\
X_{11N_{11}} & X_{12N_{12}} & & X_{1rN_{1r}} & X_{21N_{21}} & X_{22N_{22}} & & X_{2rN_{2r}}
\end{array}$$

From these numbers we compute the 2r means

$$(9.2.4) \qquad \bar{X}_{11\cdot} = \frac{1}{N_{11}} \sum_{\alpha=1}^{N_{11}} X_{11} \qquad \bar{X}_{21\cdot} = \frac{1}{N_{21}} \sum_{\alpha=1}^{N_{21}} X_{21}$$

$$\bar{X}_{12\cdot} = \frac{1}{N_{12}} \sum_{\alpha=1}^{N_{11}} X_{12} \qquad \bar{X}_{22\cdot} = \frac{1}{N_{22}} \sum_{\alpha=1}^{N_{22}} X_{22}$$

$$\cdots \qquad \cdots$$

$$\bar{X}_{1r\cdot} = \frac{1}{N_{1r}} \sum_{\alpha=1}^{N_{1r}} X_{1r} \qquad \bar{X}_{2r\cdot} = \frac{1}{N_{2r}} \sum_{\alpha=1}^{N_{2r}} X_{2r}$$

and the estimate of the common variance based on the pooled sum of squares within groups, namely,

$$(9.2.5)\quad S_W^2 = \frac{1}{N-2r}\sum_{i=1}^{2}\sum_{j=1}^{r}\sum_{\alpha=1}^{N_{ij}}\left(X_{ij\alpha} - \bar{X}_{ij.}\right)^2$$

$$= \frac{1}{N-2r}\left\{\sum_{i=1}^{2}\sum_{j=1}^{r}\sum_{\alpha=1}^{N_{ij}} X_{ij\alpha}^2 - \sum_{i=1}^{2}\sum_{j=1}^{r}\frac{T_{ij.}^2}{N_{ij}}\right\}$$

As before

$$(9.2.6)\quad T_{ij.} = \sum_{\alpha=1}^{N_{ij}} X_{ij\alpha} \qquad i = 1,2;\ j = 1,2,\ldots,r.$$

Again, there are usually three hypotheses of interest:

A) There is no main effect due to the first classificatory variable, or symbolically,

$$(9.2.7)\quad H_0^{(1)} : \alpha = 0$$

B) There are no main effects due to the second classificatory variable, or symbolically,

$$(9.2.8)\quad H_0^{(2)} : \beta_1 = \beta_2 = \ldots = \beta_r = 0$$

C) There are no interaction effects, or symbolically,

$$(9.2.9)\quad H_0^{(1\times 2)} : \gamma_1 = \gamma_2 = \ldots = \gamma_r = 0$$

If we solve equations (9.2.2) for α we have

$$(9.2.10)\quad \alpha = \frac{1}{2r}(\mu_{11} + \mu_{12} + \ldots + \mu_{1r} - \mu_{21} - \mu_{22} - \ldots - \mu_{2r})$$

That is, α is defined by a contrast of the 2r population means. We estimate α by the corresponding contrast of the sample means, namely, by

$$(9.2.11)\quad \hat{\alpha} = \frac{1}{2r}(\bar{X}_{11.} + \bar{X}_{12.} + \ldots + \bar{X}_{1r.} - \bar{X}_{21.} - \bar{X}_{22.} - \ldots - \bar{X}_{2r.})$$

The variance of the contrast is:

$$(9.2.12)\quad \sigma^2_{\hat{\alpha}} = \frac{\sigma^2}{4r^2}\left(\frac{1}{N_{11}} + \frac{1}{N_{12}} + \cdots + \frac{1}{N_{1r}} + \frac{1}{N_{21}} + \frac{1}{N_{22}} + \cdots \frac{1}{N_{2r}}\right)$$

To test the hypothesis $H_0^{(1)}: \alpha = 0$, we form the ratio

$$(9.2.13)\quad t_1 = \frac{\bar{X}_{11.} + \bar{X}_{12.} + \cdots + \bar{X}_{1r.} - \bar{X}_{21.} - \bar{X}_{22.} - \cdots - \bar{X}_{2r.}}{s_w\sqrt{\frac{1}{N_{11}} + \frac{1}{N_{12}} + \cdots + \frac{1}{N_{1r}} + \frac{1}{N_{21}} + \frac{1}{N_{22}} + \cdots + \frac{1}{N_{2r}}}}$$

When $\alpha = 0$, this ratio has a t distribution with $(N - 2r)$ degrees of freedom; the quantity t_1^2 has an F distribution with 1 and $(N - 2r)$ degrees of freedom. The hypotheses can be tested, using either a one-tailed or two-tailed test based on the t-distribution, depending upon the possible alternatives.

In determining a statistic to test $H_0^{(2)}$, we consider the following.

Suppose we write

$$(9.2.14)\quad X_{1j\alpha} = \mu.. + \alpha + \beta_j + \gamma_j + e_{1j\alpha}$$

$$X_{2j\alpha} = \mu.. - \alpha + \beta_j - \gamma_j + e_{2j\alpha} \qquad j = 1,2,\ldots,r$$

Let $$e_{ij.} = \frac{1}{N_{ij}} \sum_{\alpha=1}^{N_{ij}} e_{ij\alpha} \qquad i = 1,2,\ j = 1,2,\ldots,r$$

Then

$$(9.2.15)\quad \bar{X}_{1j.} = \mu.. + \alpha + \beta_j + \gamma_j + e_{1j.}$$

$$\bar{X}_{2j.} = \mu.. - \alpha + \beta_j - \gamma_j + e_{2j.} \qquad j = 1,2,\ldots,r$$

If we average the two sample means for each category of the second variable, we have

$$(9.2.16)\quad \frac{1}{2}(\bar{X}_{1j.} + \bar{X}_{2j.}) = \mu.. + \beta_j + \frac{1}{2}(e_{1j.} + e_{2j.}) \qquad j=1,2,\ldots,$$

For each j, the variance of the average is given by

$$(9.2.17)\qquad \frac{\sigma^2}{4}\left(\frac{1}{N_{1j}}+\frac{1}{N_{2j}}\right)=\frac{\sigma^2}{4}\left(\frac{N_{1j}+N_{2j}}{N_{1j}N_{2j}}\right)$$

It can be shown, therefore, that when the hypothesis $H_0^{(2)}$ is true, the quantity

$$(9.2.18)\qquad \frac{1}{\sigma^2}\left\{\sum_{j=1}^{r}\frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}(\bar{X}_{1j.}+\bar{X}_{2j.})^2-\frac{\left(\sum_{j=1}^{2}\frac{N_{1j}N_{2j}}{N_{1j}+N_{2j}}(\bar{X}_{1j.}+\bar{X}_{2j.})\right)^2}{\sum_{j=1}^{r}\frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}}\right\}$$

has a chi-square distribution with (r-1) degrees of freedom. It follows that if we compute

$$(9.2.19)\qquad s_2^2=\frac{1}{(r-1)}\left\{\sum_{j=1}^{r}\frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}(\bar{X}_{1j.}+\bar{X}_{2j.})^2-\frac{\left(\sum_{j=1}^{r}\frac{N_{1j}N_{2j}}{N_{1j}+N_{2j}}(\bar{X}_{1j.}+\bar{X}_{2j})\right)^2}{\sum_{j=1}^{r}\frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}}\right\}$$

when $H_0^{(2)}$ is true, the ratio

$$(9.2.20)\qquad F_2=\frac{s_2^2}{s_W^2}$$

has an F distribution with (r-1) and (N-2r) degrees of freedom. The F-test is made in the usual way.

To test the hypothesis $H_0^{(1\times 2)}$, we consider the quantities

$$(9.2.21)\qquad \frac{1}{2}(\bar{X}_{1j.}-\bar{X}_{2j.})=\alpha+\gamma_j+\frac{1}{2}(e_{1j.}-e_{2j.})\qquad j=1,2,\ldots,r.$$

That is, essentially we consider the difference in the sample means for each category of the second variable. For each j, the variance of $\frac{1}{2}(\bar{X}_{1j.} - \bar{X}_{2j.})$ is given by

$$(9.2.22)\quad \frac{\sigma^2}{4}\left(\frac{1}{N_{1j}} + \frac{1}{N_{2j}}\right) = \frac{\sigma^2}{4}\left(\frac{N_{1j}+N_{2j}}{N_{1j}N_{2j}}\right) \qquad j = 1,2,\ldots,r.$$

In this case, it can be shown, that when the hypothesis $H_0^{(1\times 2)}$ is true, the quantity

$$(9.2.23)\quad \frac{1}{\sigma^2}\left\{\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{N_{1j}+N_{2j}}(\bar{X}_{1j.} - \bar{X}_{2j.})^2 - \frac{\left(\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}(\bar{X}_{1j.} - \bar{X}_{2j.})\right)^2}{\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}}\right\}$$

has a chi-square distribution with (r-1) degrees of freedom. If we compute

$$(9.2.24)\quad s^2_{1\times 2} = \frac{1}{(r-1)}\left\{\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}(\bar{X}_{1j.} - \bar{X}_{2j.})^2 - \frac{\left(\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}(\bar{X}_{1j.} - \bar{X}_{2j.})\right)^2}{\sum_{j=1}^{r} \frac{N_{1j}N_{2j}}{(N_{1j}+N_{2j})}}\right\}$$

then when $H_0^{(1\times 2)}$ is true, the ratio

$$(9.2.25)\quad F_{1\times 2} = \frac{s^2_{1\times 2}}{s^2_W}$$

has an F distribution with (r-1) and (N-2r) degrees of freedom. The F-test is made in the usual way.

APPENDIX B

Automated teaching is the method by which you have just learned. Circle the words which would best state your position in agreement or disagreement with the following statements:

1. Automated teaching is the best method of learning for good students because they are not held back by the class.

   strongly agree agree uncertain disagree strongly disagree

2. With automated teaching, students learn a great deal because they never get left behind the class.

   strongly agree agree uncertain disagree strongly disagree

3. Automated teaching offers a challenge to the student because it makes him think.

   strongly agree agree uncertain disagree strongly disagree

4. The only way to learn is with a human teacher.

   strongly agree agree uncertain disagree strongly disagree

5. Automated teaching will ruin the educational system.

   strongly agree agree uncertain disagree strongly disagree

6. Teachers can teach much better than automated teaching.

   strongly agree agree uncertain disagree strongly disagree

7. Automated teaching helps the student to learn.

   strongly agree agree uncertain disagree strongly disagree

8. Automated teaching is a good way to learn because the student knows exactly how he is doing all the time.

   strongly agree agree uncertain disagree strongly disagree

9. Automated teaching is a boring method of learning. It offers no challenge.

   strongly agree agree uncertain disagree strongly disagree

10. Automated teaching will make robots of all the students.

    strongly agree agree uncertain disagree strongly disagree

11. There is no thinking involved in learning with automated teaching.

    strongly agree agree uncertain disagree strongly disagree

12. In automated teaching, there is never an explanation of anything.

    strongly agree agree uncertain disagree strongly disagree

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NAME_____

NUMBER_____

13. Automated teaching is the only efficient way to learn.

strongly agree agree uncertain disagree strongly disagree

14. Automated teaching is more trouble than it's worth.

strongly agree agree uncertain disagree strongly disagree

15. Automated teaching is an excellent method of learning because the student always finds out immediately whether he was right or not.

strongly agree agree uncertain disagree strongly disagree

16. Automated teaching is a good method of learning because there is no pressure on the student.

strongly agree agree uncertain disagree strongly disagree

Sets, Relations, Functions
Post Test [PTE-2]

APPENDIX C

Answer all questions in the blue book provided. Time allowed: 35 minutes.

1. Write the symbols which will represent the set of the last 2 letters of the alphabet.

2. What does "5 $\in$ A" mean?

3. Let K = {1,3,5,7,9} and let L = {0,2,5,9,13}.
   K $\cap$ L = ?

4. Let T = {1,3} and R = {1,5} and S = {1,2,3}
   T $\cup$ (R $\cup$ S) = ?

5. What is a relation?

6. {2,4} $\times$ {1,7} = ?

7. For any set A, A $\cap$ $\emptyset$ = ?

8. Let H = {(5,9),(8,11),(0,2)}
   Let G = {(11,8), (8,11), (2,0), (5,9)}
   H $\cap$ G = ?

9. Express{(5,9),(2,0),(2,4),(3,5),(6,7)} as the union of two functions.

10. If A $\subset$ B, then A $\cup$ B = ?

11. Give an example of a set T so that T $\cup$ {a,c,f} = {a,b,c,g,f}

12. Let M = {(5,7),(6,0),(2,-2)}
    Let Q = {(2,6),(7,4),(5,7),(6,4)}
    What is the image of 6 under Q?

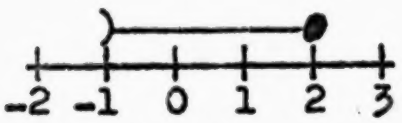
13. Let S = {(1,5),(4,1),(7,9)}
    Domain S = ?

14. Write the symbols which would represent: the set of numbers less than 3.

15. Let $H = \{(p,m) | m = p + 1\}$
What is the pre-image of 4 under H?

16. Write the graph of $\{x | x > 2\}$.

17. Let the graph of G be:



Then G = ?

18. Let $A = \{p | p > 1\}$
Write the graph of $\bar{A}$.

19. Let Q be a relation. Domain Q = Range ?

20. Give an example of a set A, so that $A \sim \{2,5,9,11\}$.

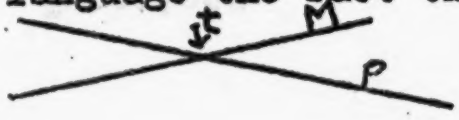
21. Let $A = \{5,9,10\}$
Let $K = \{5,7,11\}$
Let $R = \{7,10,11\}$
$A \cap (K \cup R) = ?$

22. Let $T = \{(x,y) | x > y\}$
Give <u>two</u> elements of T.

23. Let $V = \{(2,9),(5,7),(7,8),(6,4),(2,5)\}$
"V" represents the universe of discourse.
Let $A = \{(5,7),(6,4),(2,5)\}$
Let $B = \{(5,7),(2,5)\}$
$\bar{A} \cap B = ?$

24. Let $A = \{t | t \leq 4\}$
Let $B = \{t | t \geq 2\}$
Write the graph of $A \cap B$.

25. We can think of a line as a set of points. Let M and P be lines. Express in set language the fact that Line M and Line P meet at the point t.



26. List <u>all</u> the possible subsets of {1,2,3}.

27. Give an example of a function whose inverse is <u>not</u> a function.

28. Let $A - B = A \cap \bar{B}$
Let A = {a,b,c,d,e}
Let B = {a,c,d}
Then A - B = ?

29. Let G = {(x,y)|y = x + 1}
Let R = {(1,3),(2,5),(7,2)}
Then G(R(2)) = ?

30. Give examples of sets, A and B, to show that the following statement is <u>false</u>:
$A \times B = B \times A$ for all sets A and B.